Multidisciplinary Design, Analysis and Optimization: An Overview

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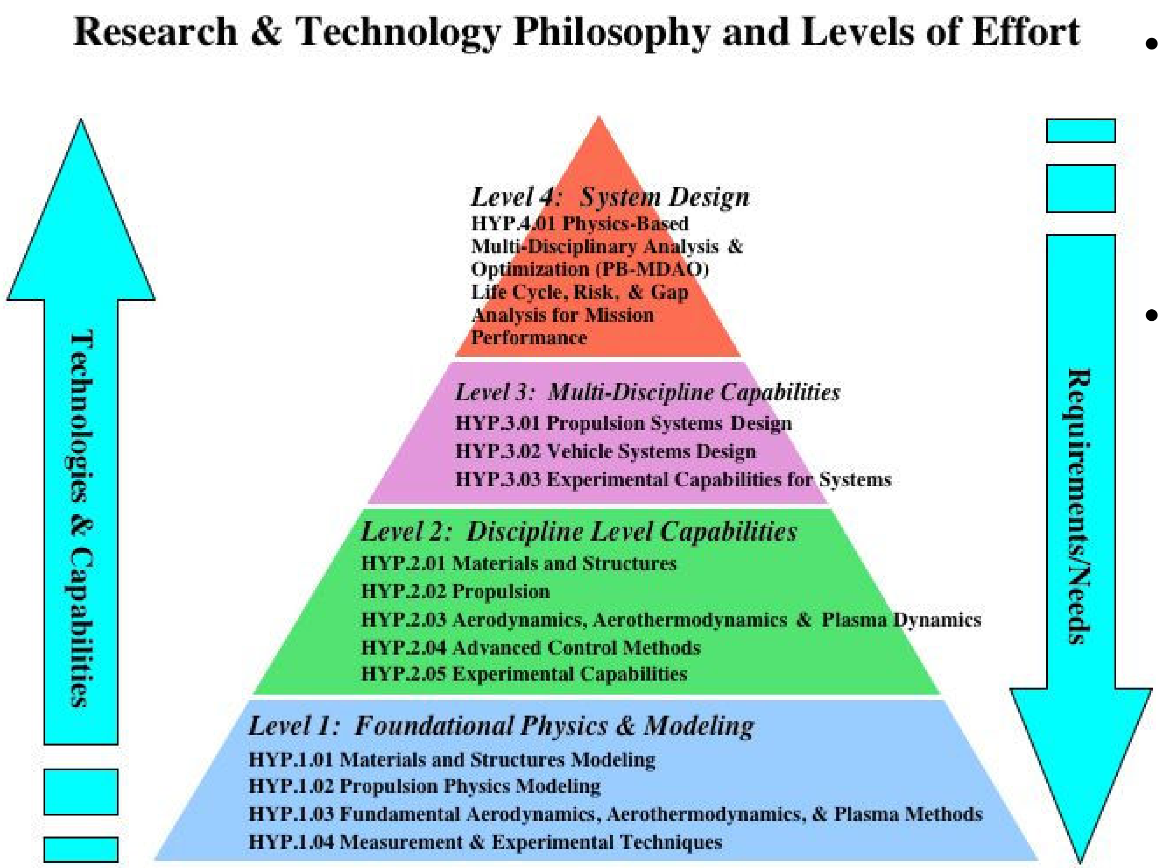
Jeff Robinson
Associate Principal Investigator for Hypersonics MDAO
NASA Langley Research Center

Outline

- Project structure and role of MDAO
- Major areas of focus in support of Highly Reliable Reusable Launch Systems (HRRLS) and High Mass Mars Entry Systems (HMMES) mission classes
  - System studies
  - Technology assessment
  - Tool and method development
- System study and tool & method development status
- Other efforts underway
- Long range milestones and plans
- Summary

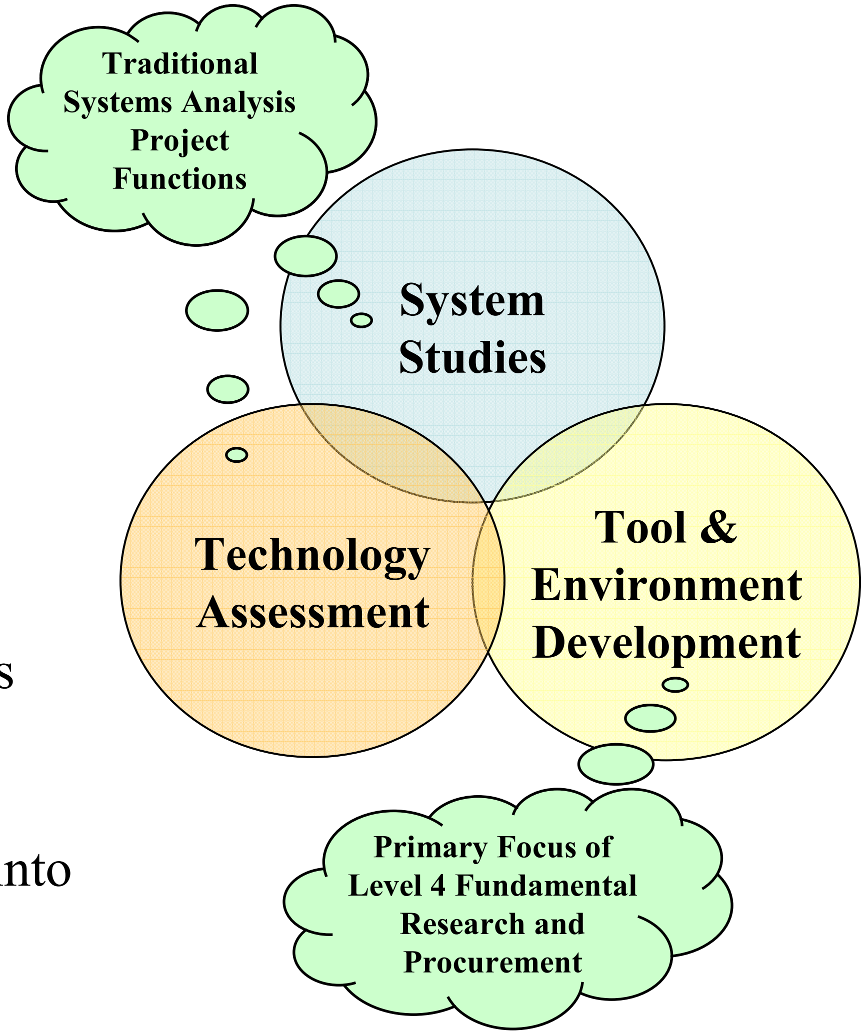
Technical Project Structure



- Four levels from foundational physics up to system design
- Guided by "push – pull" technology development philosophy; technologies & capabilities flow up, requirements flow down
- Example:
  - L1: New boundary layer transition model developed
  - L2: Incorporated into CFD code w/ increased heat transfer prediction capability
  - L3: CFD analysis coupled with TPS sizing to determine material distribution and thicknesses
  - L4: Reduced uncertainty in prediction translates to lower required margins, yielding either a lighter or more capable overall system

MDAO Project Roles

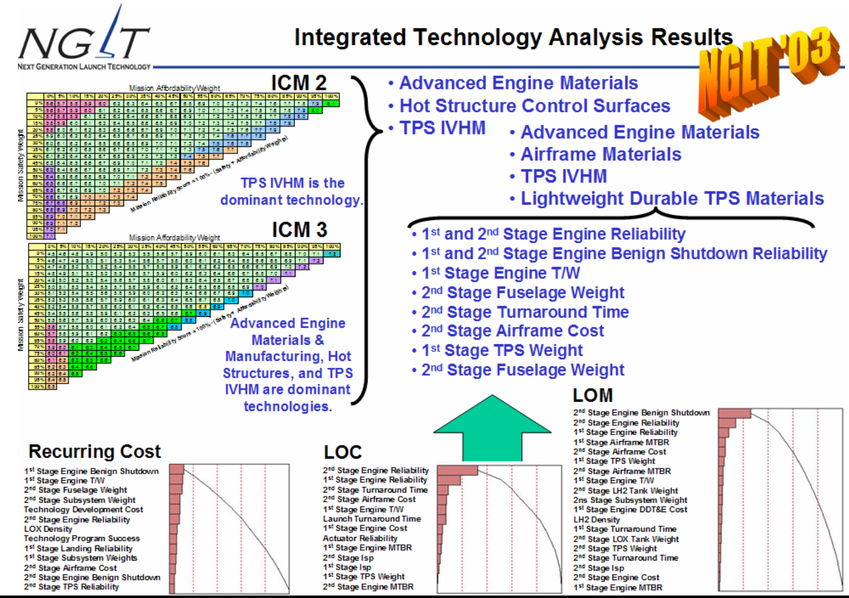
- PB-MDAO / Systems Analysis / Level 4 is a multi-center analysis organization
- Systems Analysis primary roles within
  the Hypersonics Project is to:
  - Develop reference vehicle concepts
    - HRRLS and HMMES
    - Define technology goals and requirements to lower levels.
  - Develop technology and tool metrics
    - Process uses reference vehicles
    - Process uses integrated tool set
  - Develop and/or integrate new tools into the design environment.



Technology Assessment

Objectives:

- To demonstrate the impact of discipline technologies to mission level objectives
- To provide technology “pull” guidance to disciplines
- To provide the project with information to assist with technology investment decisions



Status:

- Initial HRRLS technology assessment to commence following completion of initial TSTO system study
- Currently gathering technology data inputs from disciplines
- Also expecting NRA to provide improved tech assessment tools and tech database management

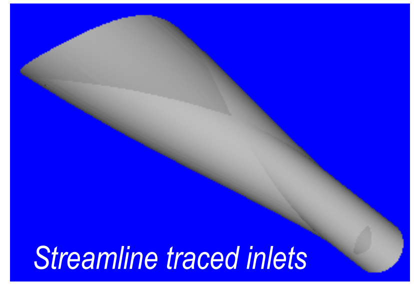
FY 2008/09 Key Deliverables and Milestones:

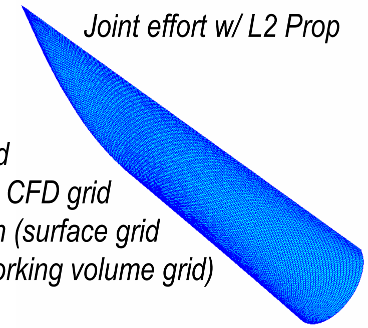
- Technology assessment for HRRLS concept due FY08Q1; deliverable includes report on technologies assessed, their modeling & impacts and related sensitivity and uncertainty analyses
- Assessment for alternate concept due FY09Q1
- Technology assessment for HMMES concept due FY08Q3; assessment for alternate concept due FY08Q3

Tool & Method Development

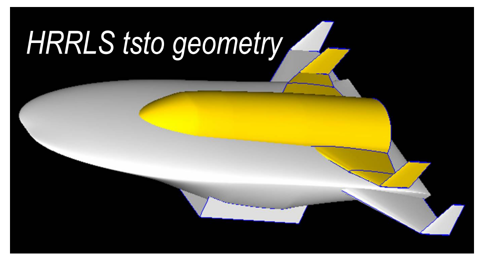
Objectives:

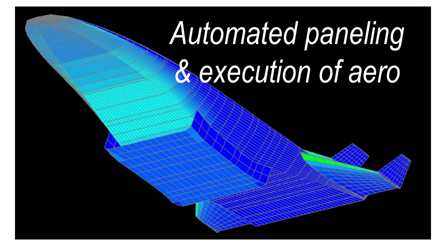
- To develop a geometry centric integrated design, analysis & optimization environment
  - Support multi-fidelity analysis
  - Rapid uncertainty analysis / assessment
  - Flexible and robust
  - Incorporate existing discipline tools
- To improve and/or streamline individual discipline tools, such as “life cycle” models for hypersonic systems
- To identify and fill gaps in tool suite





Automated structured CFD grid generation (surface grid shown, working volume grid)





Status:

- HRRLS environment: currently integrating trajectory, aero, geometry, packaging, and sizing for upper stage; structures, packaging, propulsion and sizing for first stage
- HMMES environments: developing rapid aeroheating analysis tool; also working on environment for ballute design
- Also working automated structured CFD grid generation, STI inlets for HRRLS

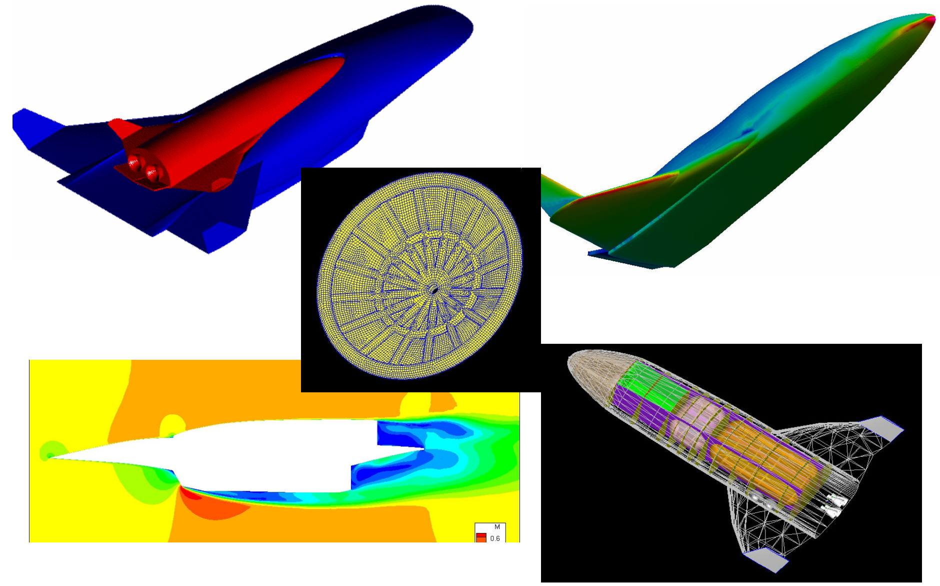
FY 2008/09 Key Deliverables and Milestones:

- HRRLS Integrated Environment Generation 1, due 9/09
  - Generation 1 will be for 2-D class of vehicle, others to follow (waverider, STI)
- Automated CFD grid generation due FY08Q4
- NRA to provide improved uncertainty quantification and related tools; improved life cycle models
- Several EDL tool development efforts underway

System Studies

Objectives:

- To perform system studies in support of the HRRLS and HMMES missions, which provides:
  - Reference concepts for other disciplines to analyze / exercise tools and apply technologies
  - A mechanism by which to exercise and evaluate MDAO tools; gage improvement in cycle time, etc
  - Reference concepts on which to perform technology assessment for the project, providing technology investment guidance



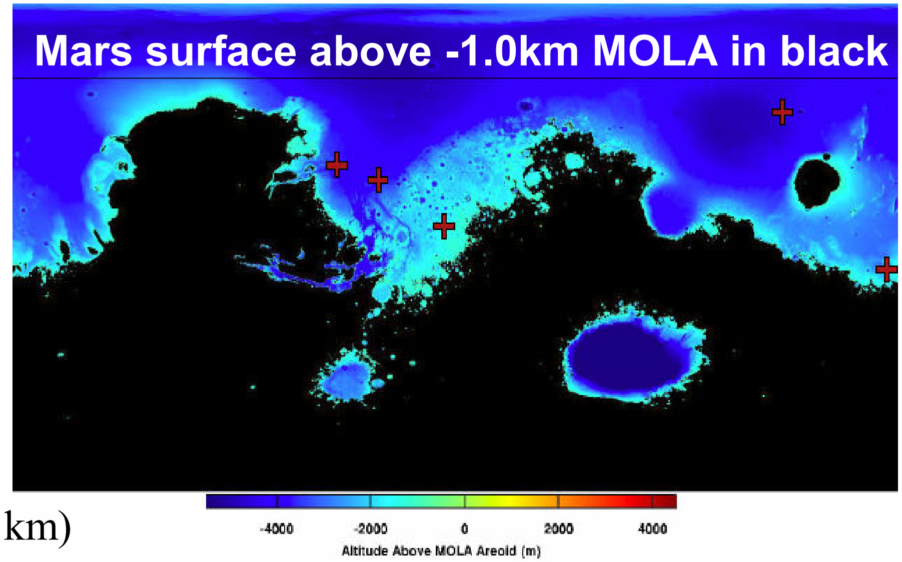
Status:

- HRRLS system study in progress
  - RP/LOX & H2/LOX upper stages sized & closed
  - Aero for 1st stage & mated config. nearly complete
  - Uncertainty assessment also in progress (aero)
  - Trajectory & vehicle closure beginning
  - FY08 will incorporate higher fidelity
- HMMES study coordinated w/ Mars Arch. Team
  - DRM 5.0 reference system available soon
  - Trade studies to follow

FY 2008/09 Key Deliverables and Milestones:

- Initial TSTO system closures, to be completed shortly; deliverable includes vehicle model data, flight environments, loads, etc.; Updated TSTO, due 6/08; alternate concept to be developed, due 6/09
- Initial HMMES concept, due 1/08, based on recommendations from Mars Architecture Team (MAT) study; alternate HMMES concept due 1/09

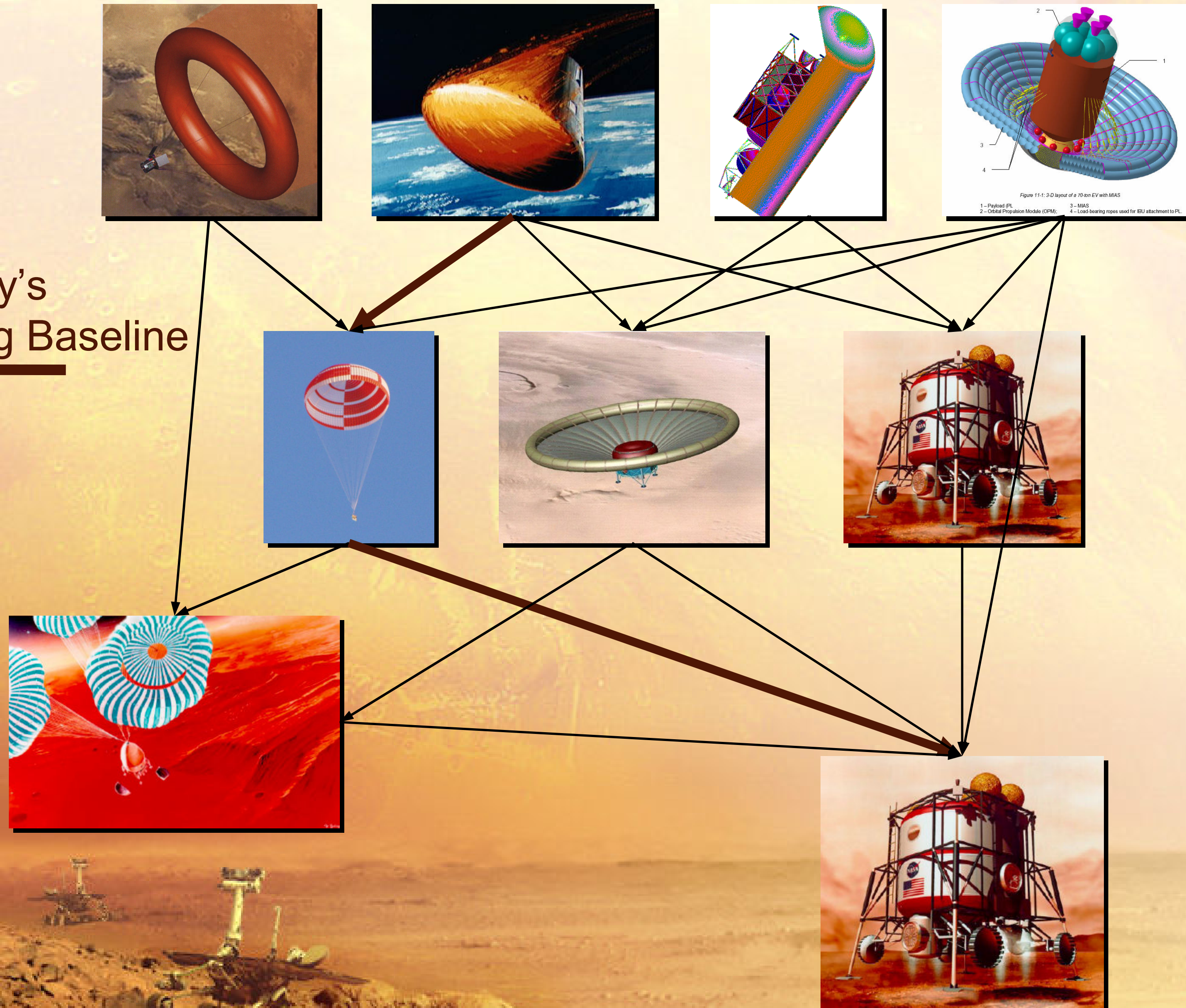
Why High Mass Mars Entry Systems?



- Only five successful U.S. landings on Mars:
  - Vikings I and II (1976)
  - Mars Pathfinder (1997)
  - Mars Exploration Rovers, Spirit and Opportunity (2004)
- All five of these successful systems:
  - Had landed masses of less than 0.6 MT
  - Landed at low elevation sites (below –1 km MOLA)
  - Had large uncertainty in landing location (uncertainty in targeting landing site of 100s km)
- All of the current Mars missions have relied on large technology investments made in the late 1960s and early 1970’s as part of the Viking Program
  - Aerodynamic characterization of 70-deg sphere cone forebody heatshield
  - SLA-561V TPS
  - Supersonic disk-gap-band parachute
  - Autonomous terminal descent propulsion
  - MSL relying on modified Viking engines
- Studies show requirements for landing large robotic or human missions on Mars include landing 40-80 MT payloads with a precision of tens of meters, possibly at high altitude. Studies also indicate that these requirements can not be met with Viking era technology.

HMMES System Studies

Today's Viking Baseline



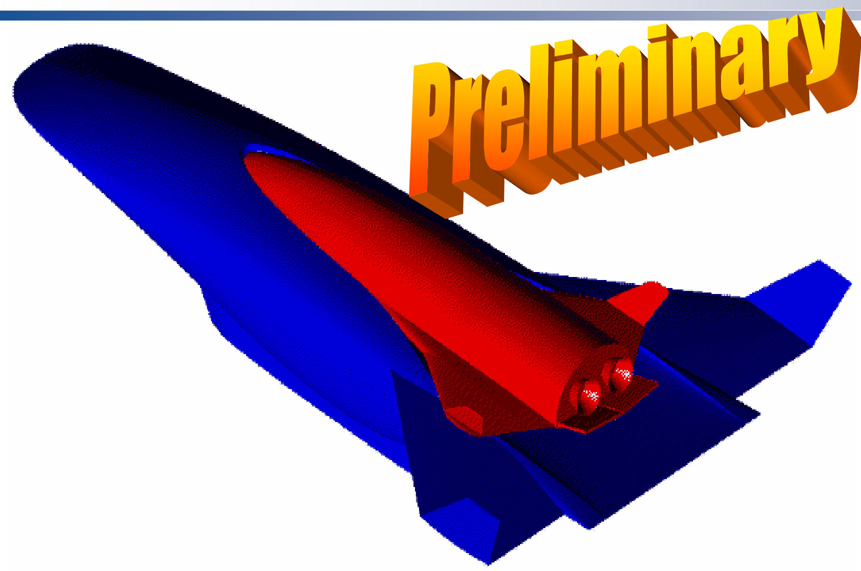
Options for Hypersonic Decelerators

Options for Supersonic Decelerators

Options for Subsonic Decelerators

Options for Terminal Descent Systems

HRRLS Vehicle Concept & Technology Suite



- **Architecture Information**
  - TSTO-horizontal takeoff & landing
  - 2-D lifting body booster, fully reusable winged-body rocket upper (will also examine expendables)
  - Booster initially all HC fueled, will examine dual fuel (HC & H2) as well as all H2
- **Reference Mission Characteristics**
  - Payload Mass: 10,000 lbs + 4 crew
  - Payload Dimension: 12 x 12 x 20 ft
  - Launch & landing site: KSC
  - Orbit: 50x160 nmi, 28.5° inclination
  - Supports baseline Exploration LEO rendezvous scenario (TRL=6 by 2017, IOC 2025)

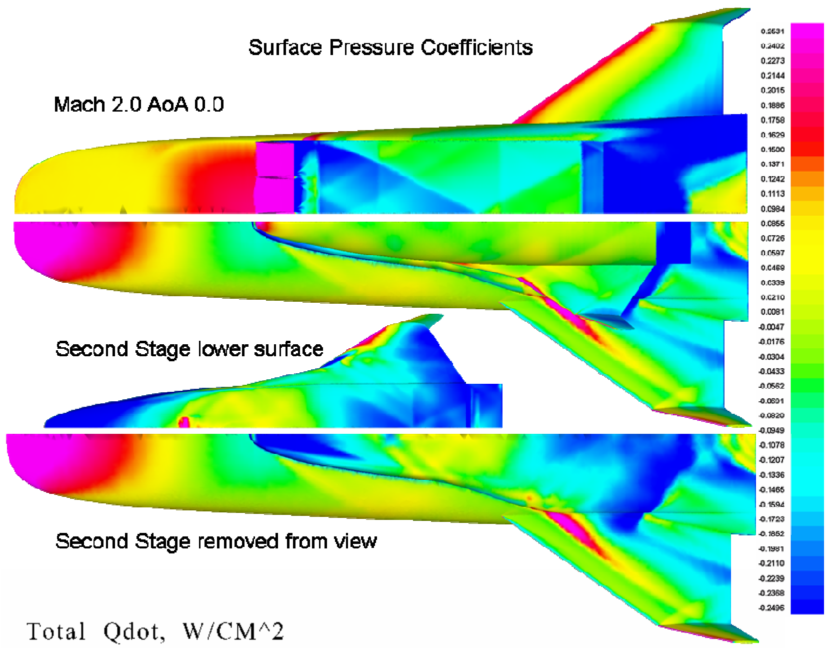
- **Airframe Technology Suite**

  Booster & Orbiter
  - Ti-Al or Al-Li primary structure
  - (Booster) Integral conformal Al-Li HC tanks
  - (Booster) Multi-lobed Al-Li LOX tank (if rocket req'd)
  - (Orbiter) Multi-lobed Al-Li H2 (~5 psia) and LOX tanks (~30 psig)
  - AETB-8 ceramic composite tile and TABI blanket TPS
  - Advanced polyimide foam (APF) insulation on tanks
  - High temperature metallic wings, tails and control surfaces
  - Coated carbon-carbon leading & trailing edges

- **Propulsion Technology Suite**
  - Lowspeed (Mach 0-3.5)
    - F135 advanced derivative afterburning turbojets
    - In over-under configuration with high speed propulsion system
  - Highspeed (Mach 3-8)
    - Fully variable geometry dual mode scramjet (inlet flap rotation, cowl vertical translation)
    - Mach 7 shock-on-lip, actively cooled, high temperature metallics
  - External Rocket System
    - Booster will potentially require tail rocket system to assist with takeoff, transonic, and staging
  - Upper stage rocket
    - Conventional liquid; looking at RP/LOX & H2/LOX

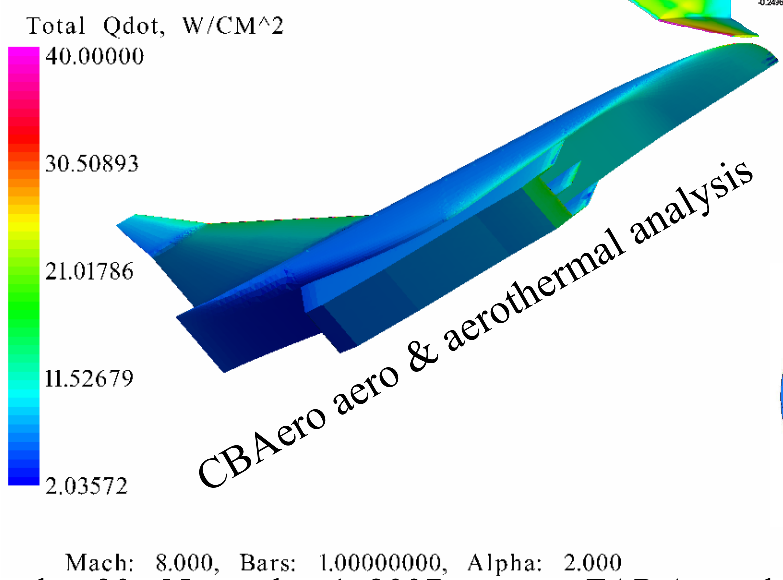
TSTO: Mated & Booster Analysis

Cart3d flow-through aerodynamic analysis

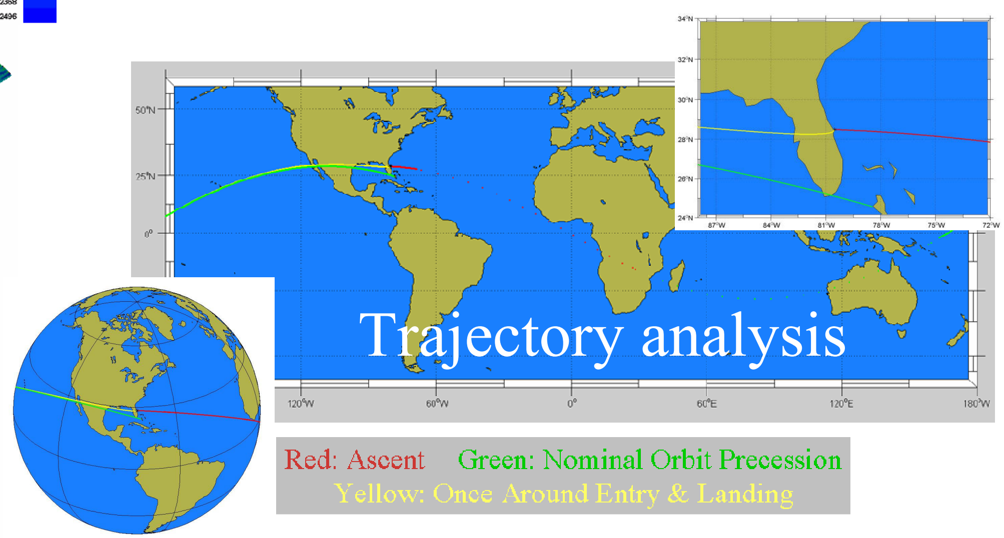


HRRLS TSTO system study in progress

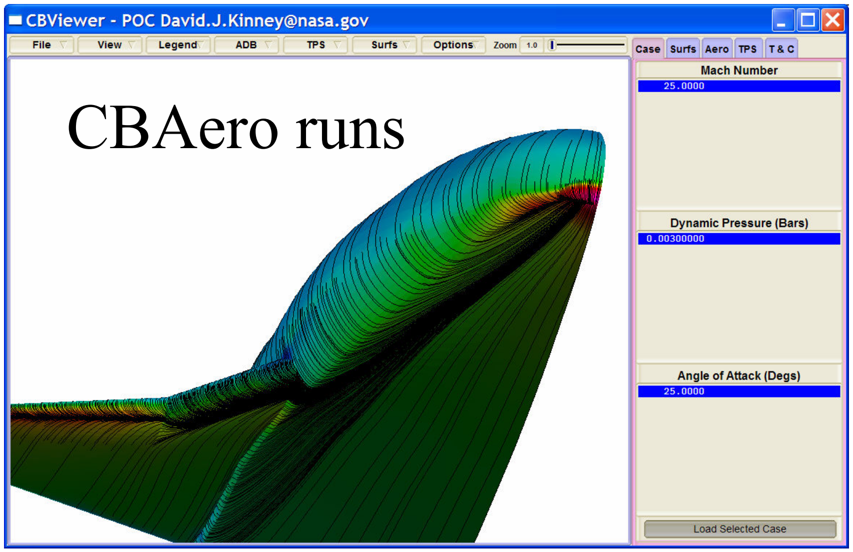
- RP/LOX & H2/LOX upper stages sized & closed; thermal analysis & TPS sizing underway
- Aero for 1st stage & mated config. near complete
- Trajectory & sizing beginning for combined sys
- FY08 will incorporate higher fidelity (structural analysis, installed lowspeed performance, thermal & power balance, flowpath mechanical design, uncertainty analysis)
- Uncertainty assessment of analytical methods also in progress; beginning w/ aero, will continue w/ thermal, propulsion, etc.

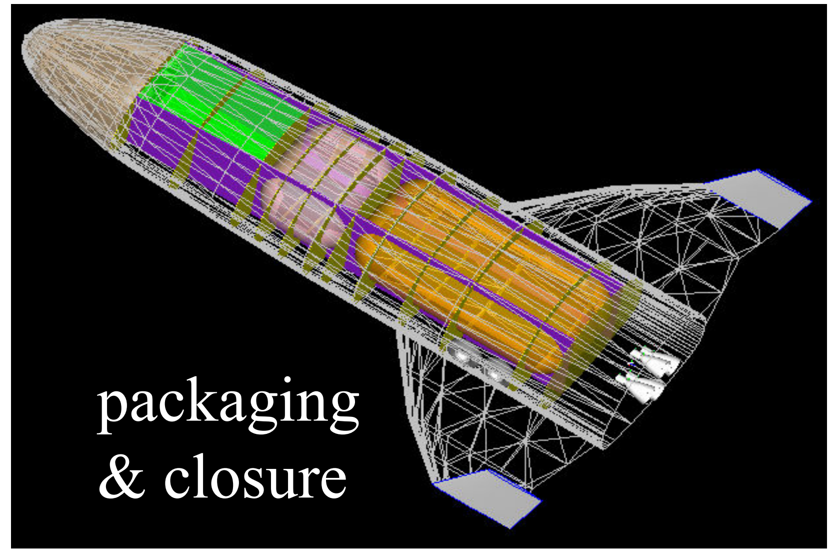


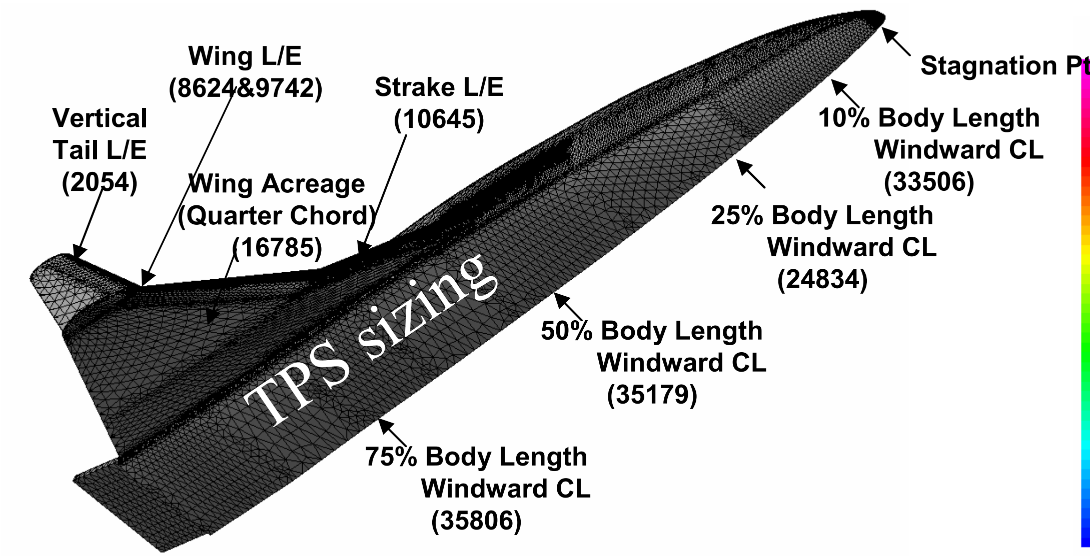
CBAero aero & aerothermal analysis

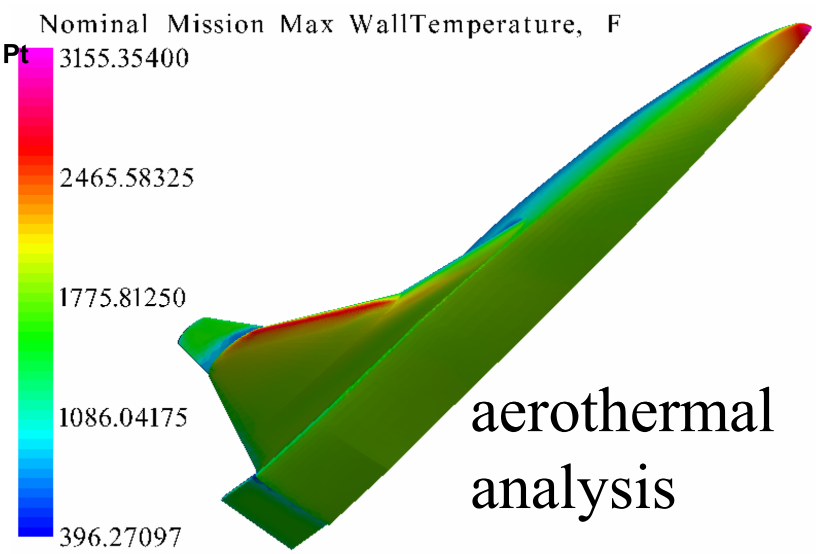


TSTO: Upper Stage Analysis



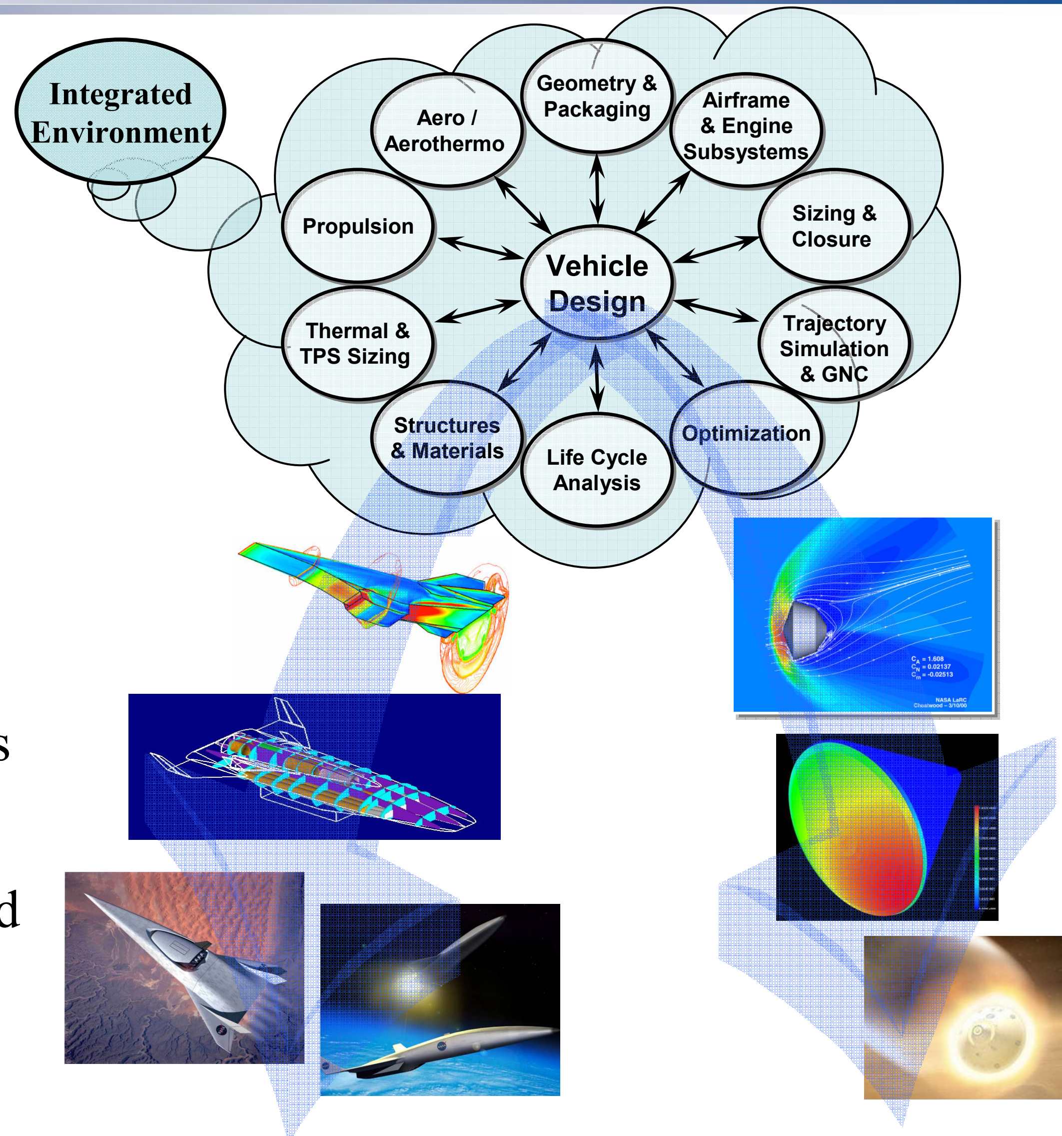






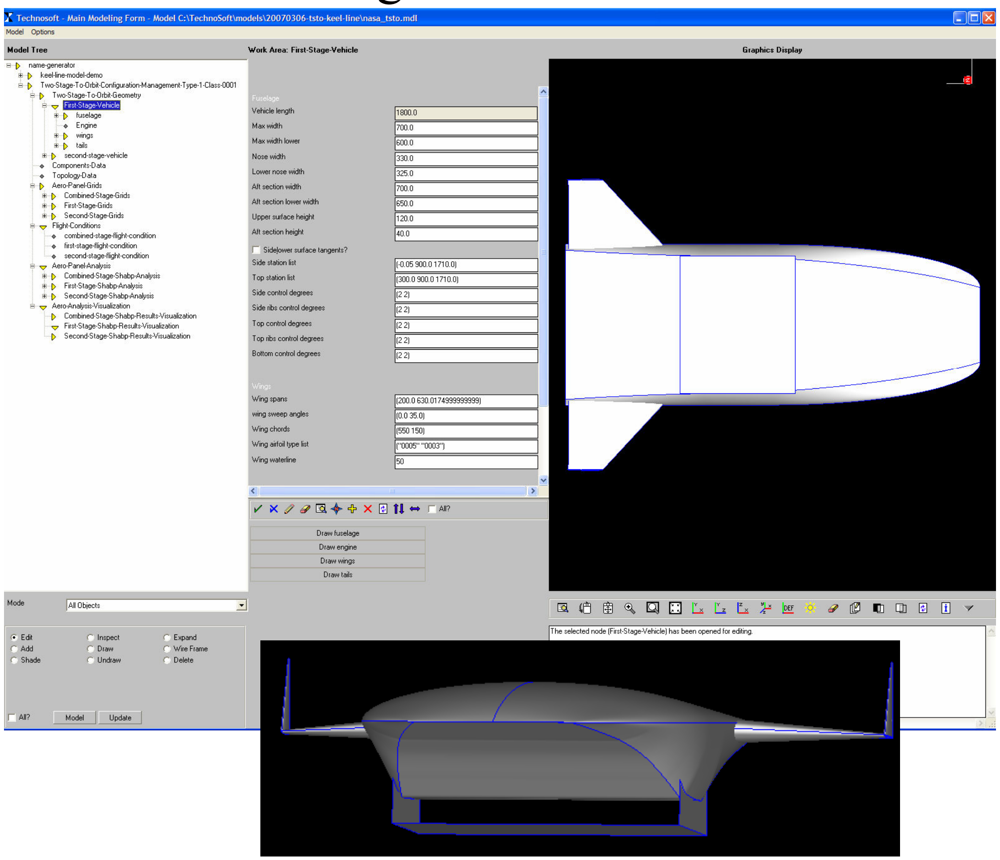
MDAO Tool & Method Development

- Our objective is to improve system level design and analysis capability enabling faster solutions with increased accuracy and fidelity
- Major focus on integrating all required discipline tools into design environment
- Environment development underway for HRRLS and HMMES mission classes
- First step was to survey and categorize current suite of tools in terms of discipline and fidelity level
- Efforts underway internally and through NRA process to fill gaps in tool suite and improve tools with known deficiencies.

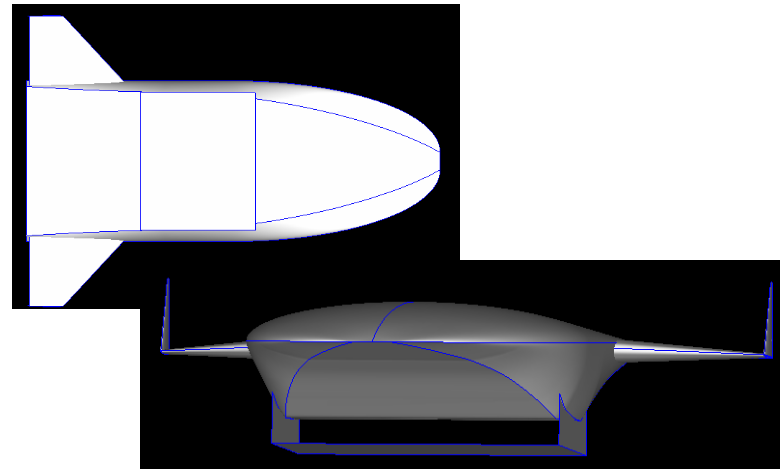


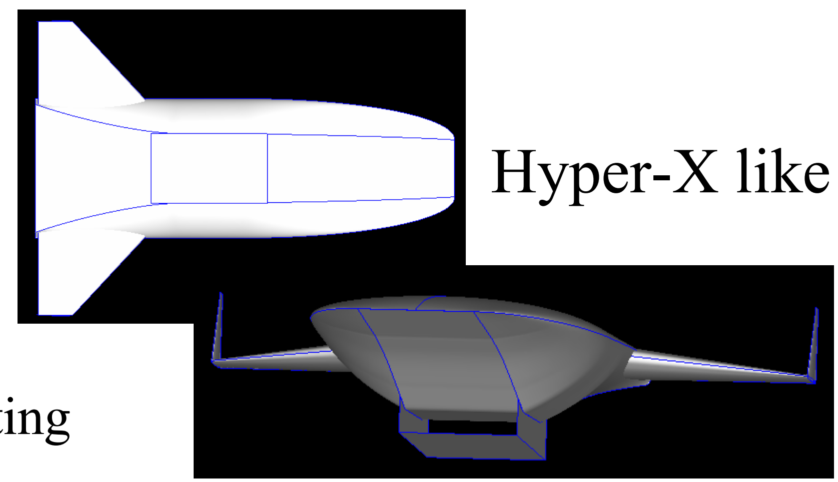
OML Shaping Capability w/ 2-D Lifting Body Class

Changes achieved by varying four parameters;
OML regenerated in seconds



NASP-like shapes



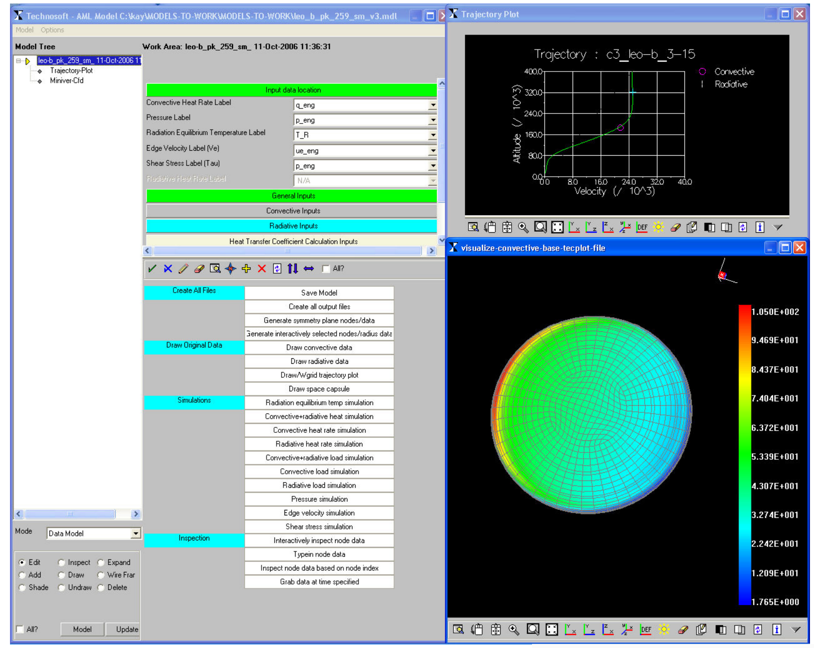


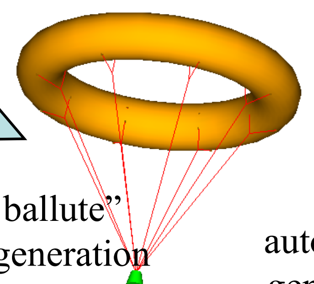
Hyper-X like

Work will continue with vehicles incorporating
ITI/STI inlets, waveriders, other planforms

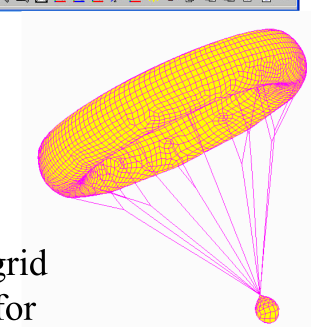
HMMES Design & Analysis Environments

- Several efforts are underway on integrated tool environments for HMMES
- One focusing on rapid aero-heating analysis (currently for capsules, but extendable to other types of designs); next phase will incorporate TPS sizing and trajectory analysis
- Another focused on ballute designs which is currently working geometry generation and interface with structural analysis; next phase will incorporate aero and trajectory
- Both systems can be combined with some work as well as incorporating modules developed for HRRLS (aero, trajectory, etc) to build HMMES design environment



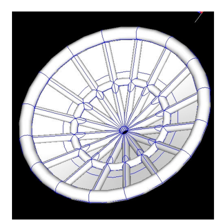


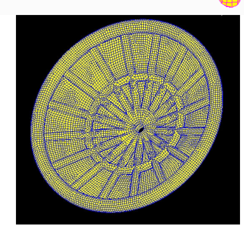
“trailing ballute” geometry generation



automated grid generation for NASTRAN

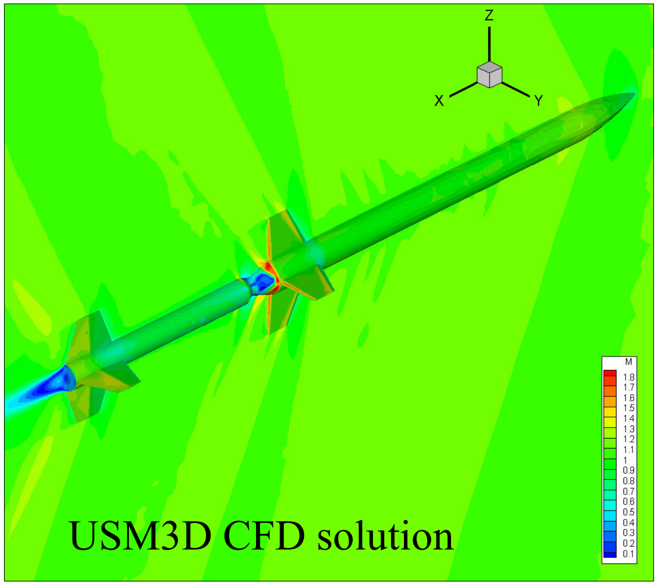
“attached ballute” geometry generation

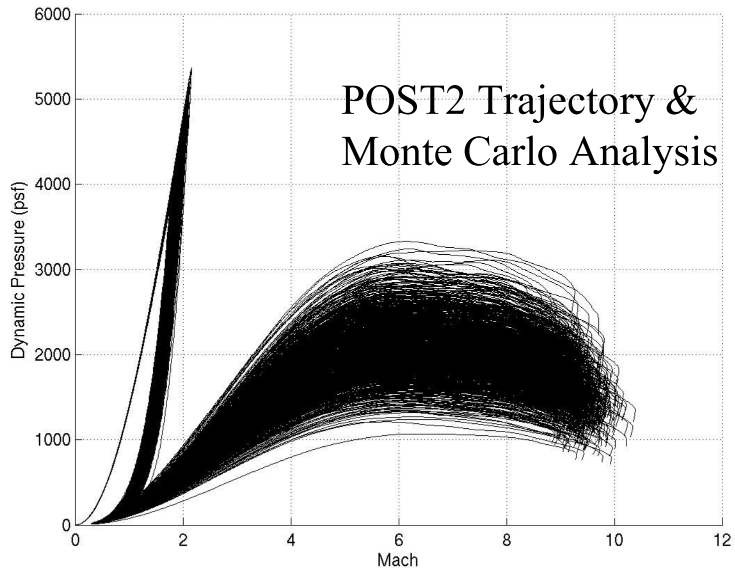




HIFIRE Special Project Support

- Level 4 has been supporting the HIFIRE flight test series with aerodynamic database development and trajectory analysis
- Baseline aero database generated with USM3D
- Trajectory & Monte Carlo analysis performed using POST2
- Also worked to improve design and analysis tools
  - Rapid missile geometry generation
  - Automated execution of Missile Datcom
  - Automated generation of paneled surfaces for APAS/SHABP, tetrahedral grids for CFD (.stl format), and IGES surfaces
  - Automated execution of Monte Carlo trajectory runs

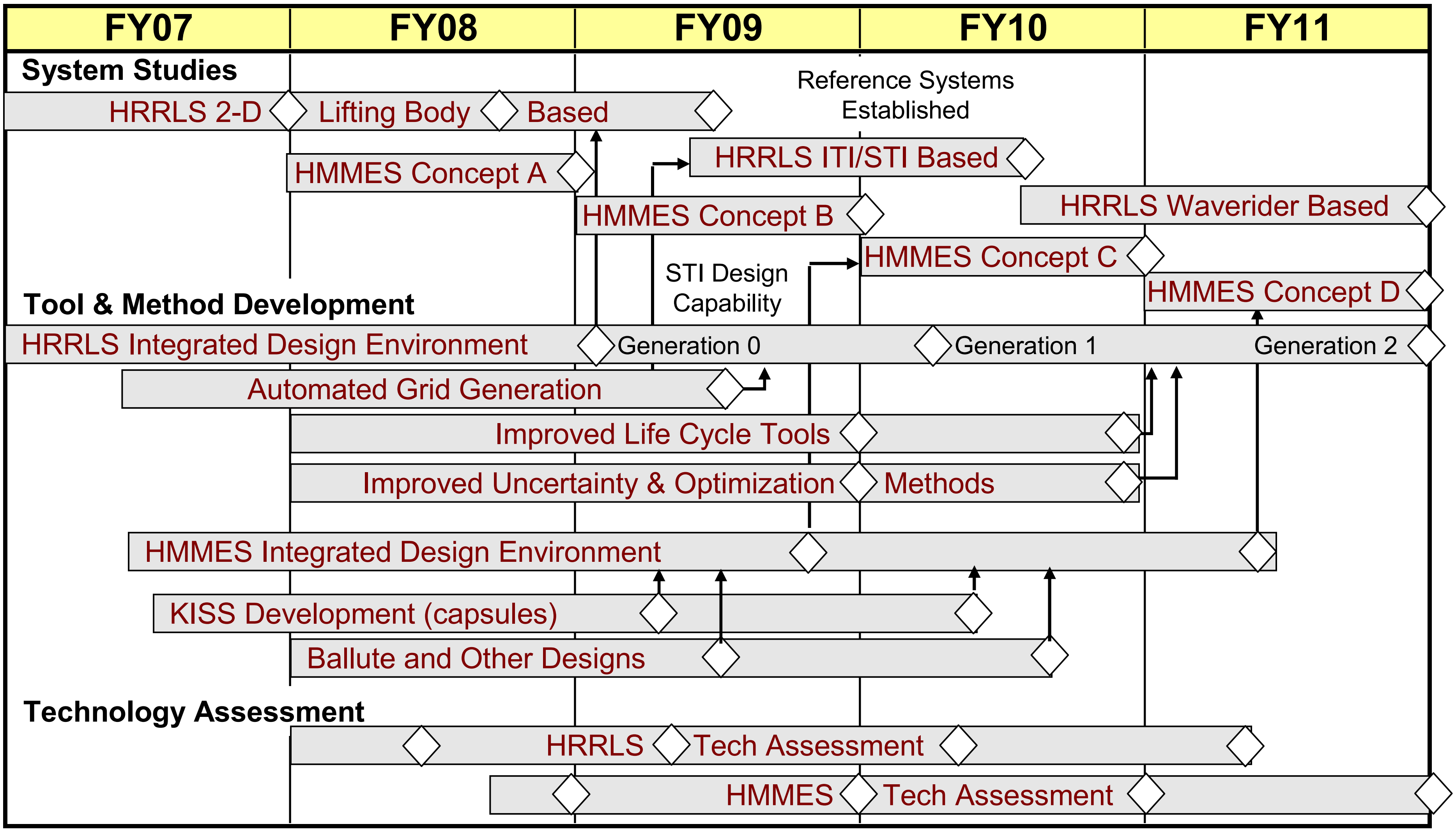




2007 MDAO HRRLS NRA Summary

- Hypersonics MDAO solicited proposals in six subtopic areas related to HRRLS mission class
- Five proposals were selected for award; breakdown is as follows:
  - **(1)** Subtopic A.5.8.1: Improved Life Cycle Tools for Conceptual Systems
    - *Objective*: To develop improved life cycle tools for conceptual hypersonic system designs, including cost models, safety & reliability, operability, etc. including uncertainty and V&V of such tools
  - **(2)** Subtopic A.5.8.2: Uncertainty Quantification and Propagation Methods and Tools for System Level Analysis
    - *Objective*: To develop and incorporate tools and methods for the quantification and propagation of uncertainty from component and subsystem levels to the system level and figures of merit as well as strategies for managing and designing for uncertainty
  - **(1)** Subtopic A.5.8.3: Intelligent Data Integration
    - *Objective*: To develop methodologies allowing the integration of data sets, likely of varying levels of fidelity, from multiple sources into a single data set. Also of interest is the uncertainty of the integrated data set and methods for provide guidance as to what higher fidelity cases should be run to reduce the uncertainty of the data set.
  - **(1)** Subtopic A.5.8.6: Design Methods
    - *Objective*: To understand and improve current design methods and processes including those that reduce design cycle time, incorporate factors other than performance (such as risk, funding profiles, use of new technology vs heritage systems) and optimization in the presence of uncertainty

MDAO Long Range Milestones



Summary

- MDAO tasks in three major areas: system studies, technology assessment and tool & method development
- Efforts focused in support of two primary mission classes: Highly Reliable Reusable Launch Systems (HRRLS) and High Mass Mars Entry Systems (HMMES)
- Considerable progress in HRRLS system study and in integrated environment development for both mission classes, as well as support of HIFIRE special project
- NRA awards soon; will provide significant support to milestones